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Kang

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(54) **METHOD OF REDUCING NOISE IN IMAGE AND IMAGE PROCESSING APPARATUS USING THE SAME**

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(22) Filed: **Sep. 30, 2014**

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(30) **Foreign Application Priority Data**

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G06T 5/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G06T 5/002*** (2013.01); *G06T 2200/04* (2013.01)

(58) **Field of Classification Search**
CPC G06T 5/002; G06T 2207/20012; G06T 2207/20032; G06T 5/20; G06K 9/40; H04N 5/357
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,139,891 B2		3/2012	Chang et al.	
2004/0126033	A1*	7/2004	Ishizaka	382/254
2007/0196031	A1*	8/2007	Chen et al.	382/278
2009/0161982	A1*	6/2009	Tico et al.	382/275
2010/0020341	A1*	1/2010	Enjuji	358/1.9
2010/0141804	A1*	6/2010	Morel et al.	348/241
2011/0097008	A1*	4/2011	Cao et al.	382/260
2011/0142368	A1*	6/2011	Shin et al.	382/275
2011/0229029	A1	9/2011	Kass	
2012/0308104	A1	12/2012	Yang et al.	
2013/0314557	A1*	11/2013	Furukawa	348/208.1
2014/0118578	A1*	5/2014	Sasaki et al.	348/241
2014/0118581	A1*	5/2014	Sasaki et al.	348/242
2014/0193082	A1*	7/2014	Ohnuki et al.	382/205
2014/0218571	A1*	8/2014	Cheng	348/273
2015/0187053	A1*	7/2015	Chen et al.	

FOREIGN PATENT DOCUMENTS

KR	1019970701897 B1	2/1997
KR	1020120017521 A	2/2012

* cited by examiner

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(57) **ABSTRACT**

Provided are methods and apparatuses for reducing noise in an image, in which a kernel that gives a weight to a pixel value with respect to determination of a similarity between patches is adaptively changed according to a reference patch, a non-transitory computer-readable storage medium for recording the same, and an image processing apparatus using the same, in which noise in an image is removed according to a noise removal algorithm based on non-local means.

18 Claims, 6 Drawing Sheets

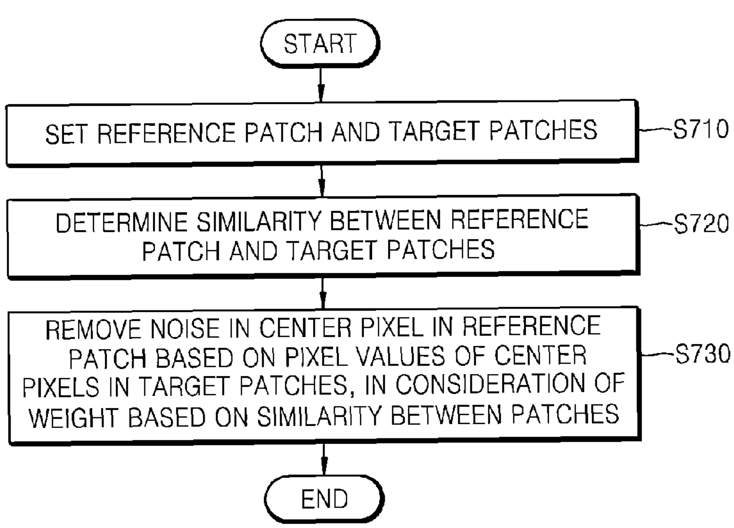


FIG. 1

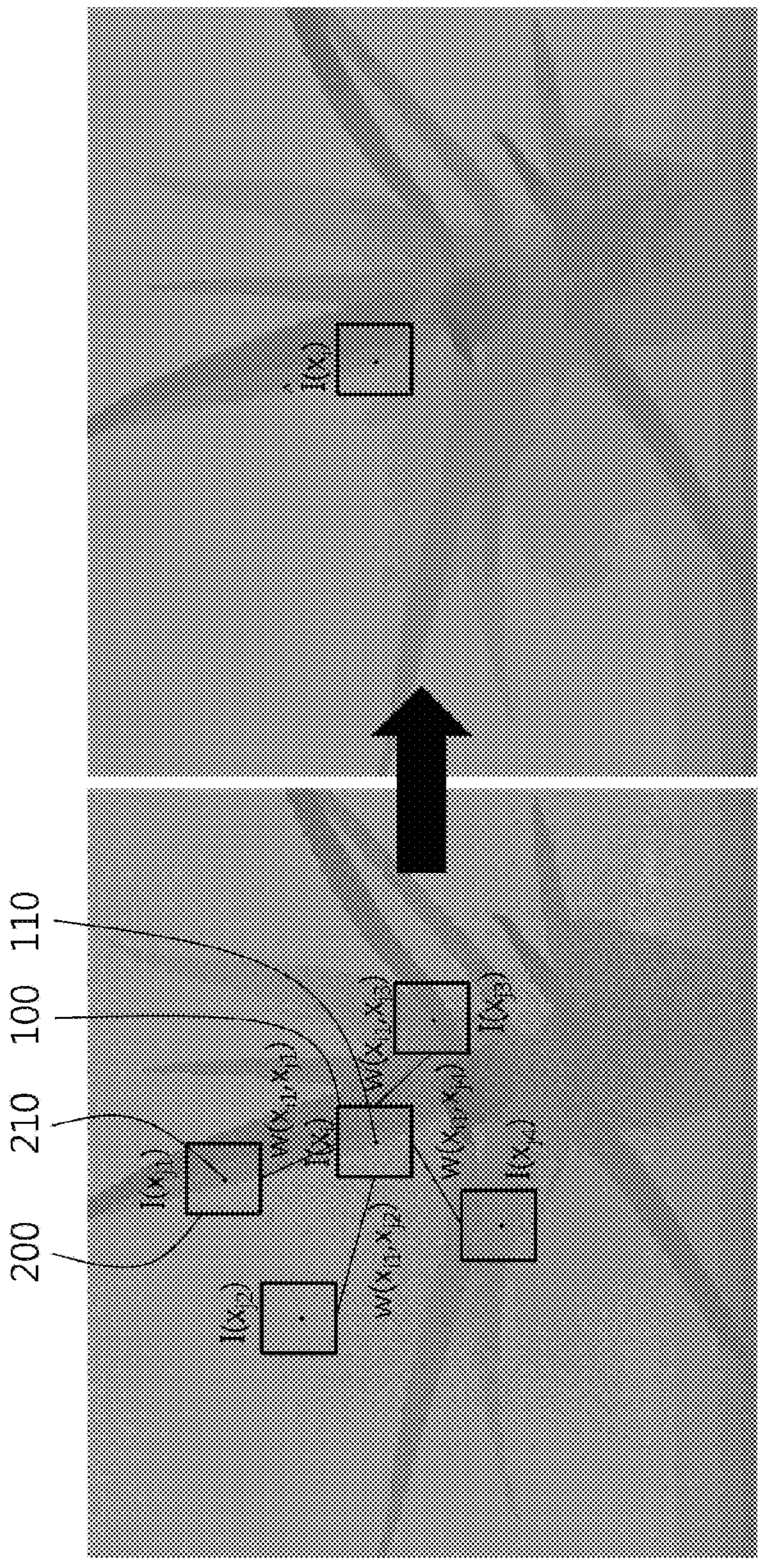


FIG. 2

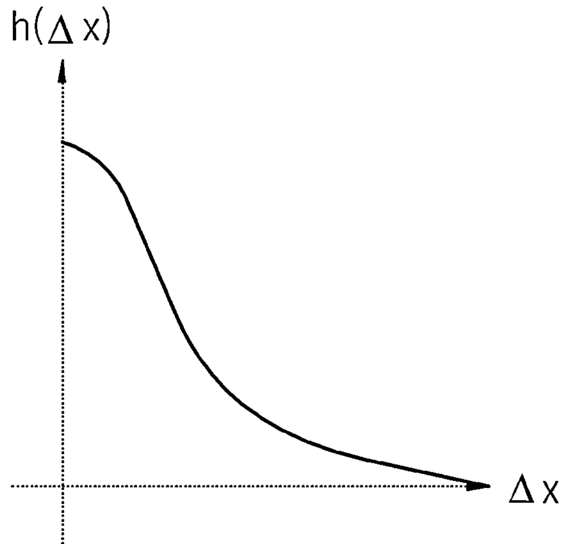


FIG. 3

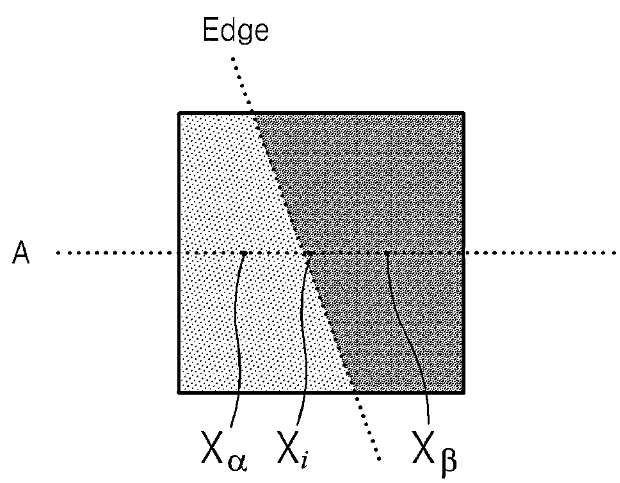


FIG. 4

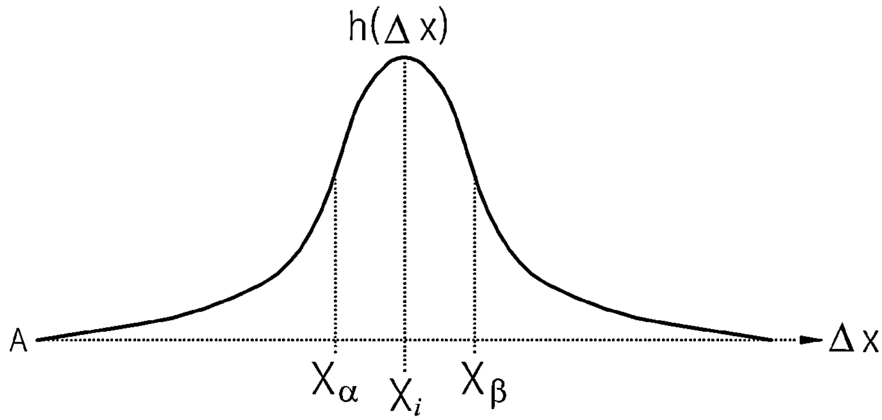


FIG. 5

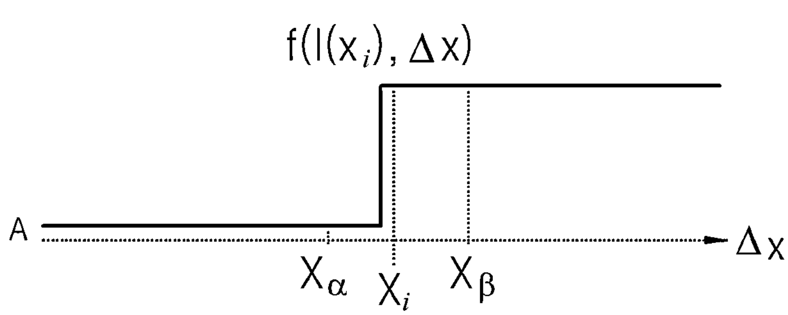
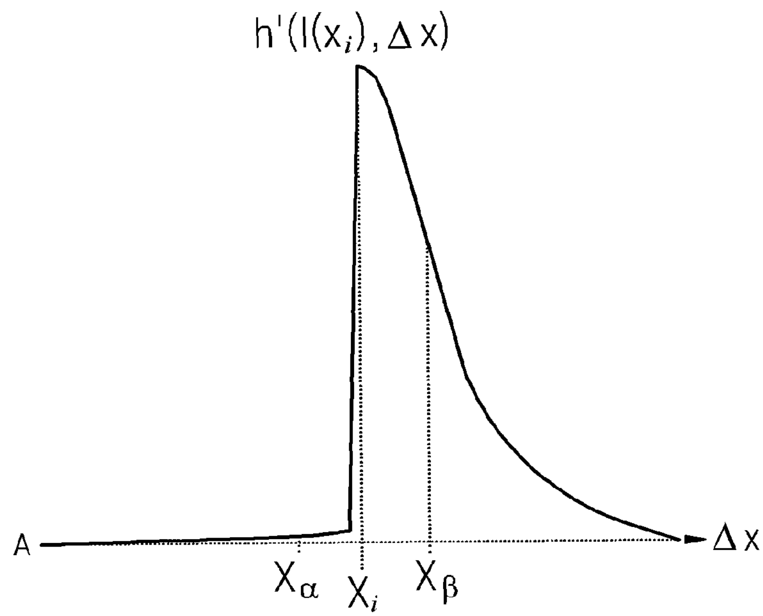
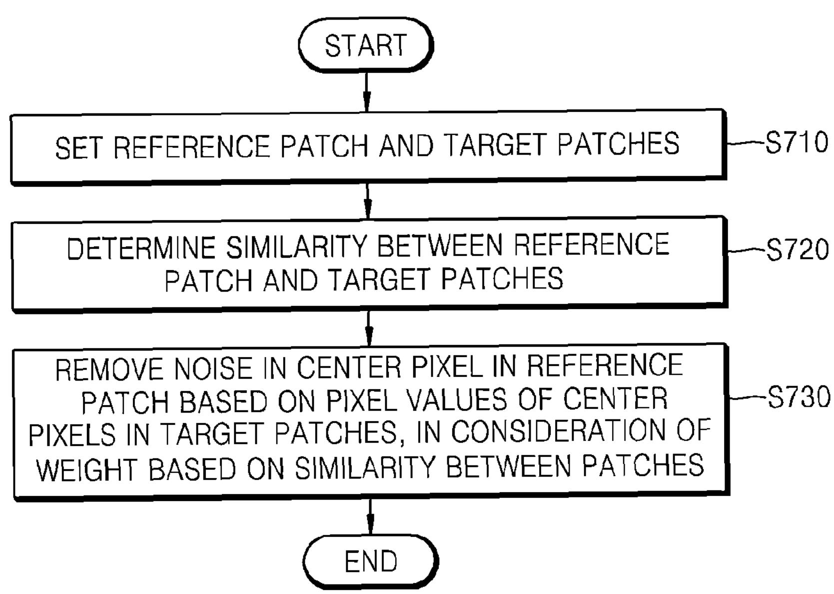


FIG. 6



h'(I(x_i), Δx)
A
Δx
X_α
X_i
X_β

FIG. 7



START
SET REFERENCE PATCH AND TARGET PATCHES
S710
DETERMINE SIMILARITY BETWEEN REFERENCE PATCH AND TARGET PATCHES
S720
REMOVE NOISE IN CENTER PIXEL IN REFERENCE PATCH BASED ON PIXEL VALUES OF CENTER PIXELS IN TARGET PATCHES, IN CONSIDERATION OF WEIGHT BASED ON SIMILARITY BETWEEN PATCHES
S730
END

FIG. 8

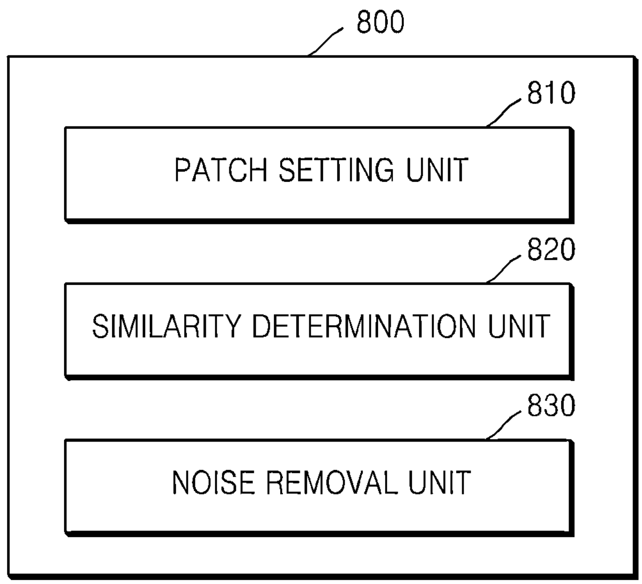

800
810
PATCH SETTING UNIT
820
SIMILARITY DETERMINATION UNIT
830
NOISE REMOVAL UNIT

FIG. 9

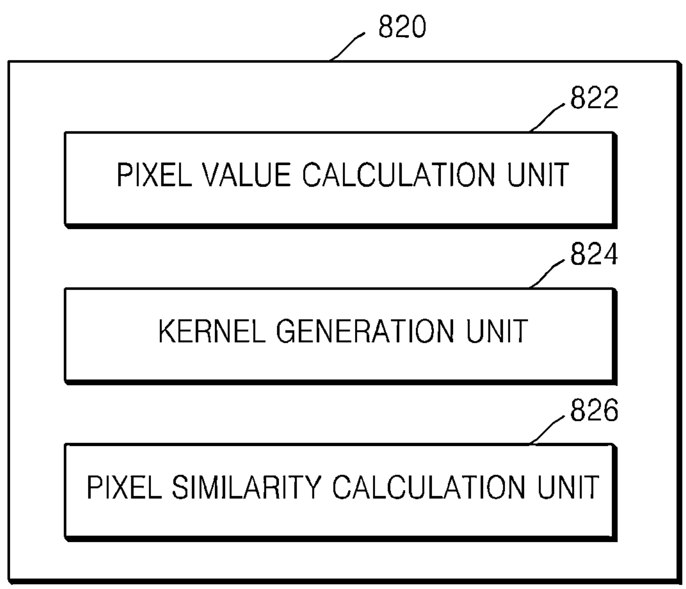
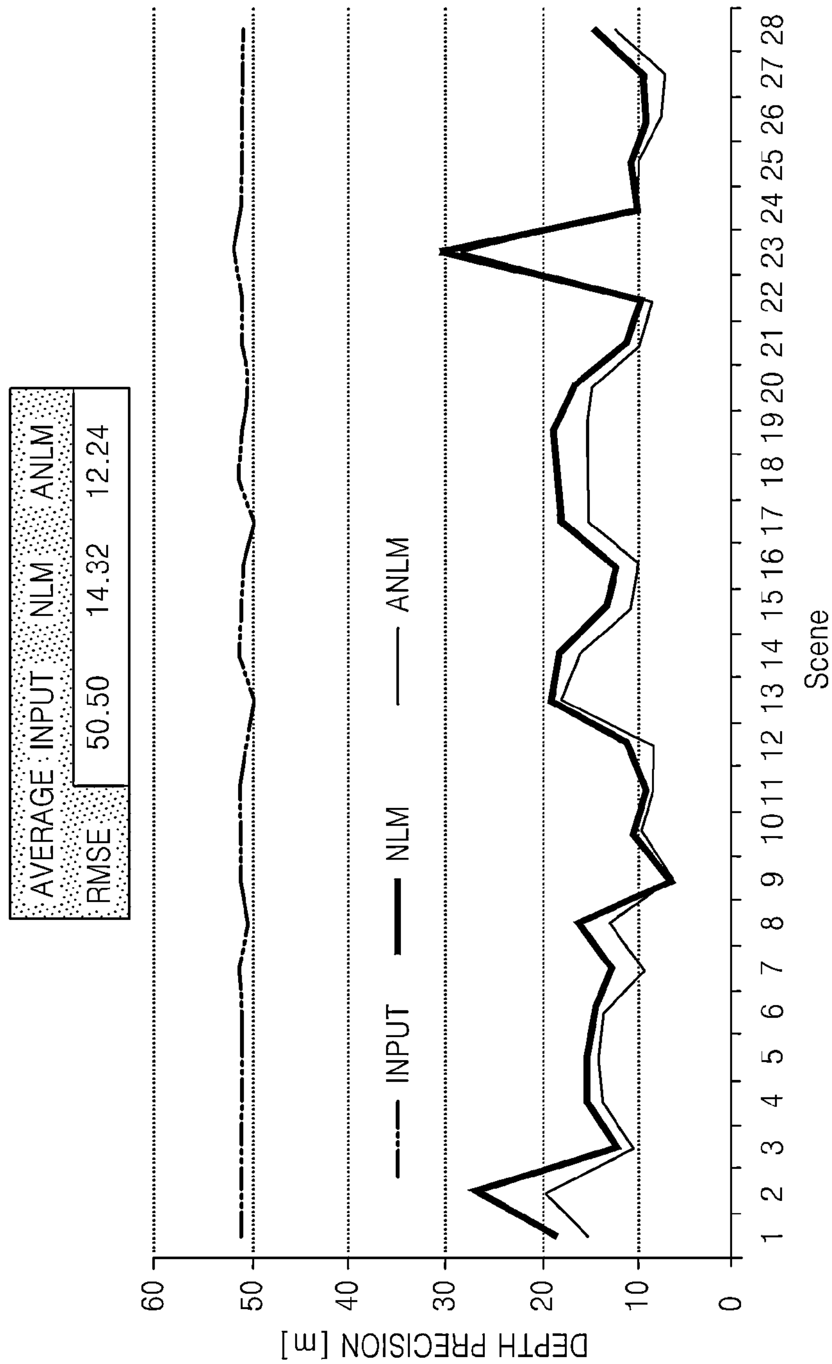

820
822
PIXEL VALUE CALCULATION UNIT
824
KERNEL GENERATION UNIT
826
PIXEL SIMILARITY CALCULATION UNIT

FIG. 10



AVERAGE INPUT NLM ANLM
RMSE 50.50 14.32 12.24
INPUT
NLM
ANLM
DEPTH PRECISION [m]
0
10
20
30
40
50
60
Scene
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

METHOD OF REDUCING NOISE IN IMAGE AND IMAGE PROCESSING APPARATUS USING THE SAME

RELATED APPLICATIONS

This application claims the benefit of Korean Patent Application No. 10-2013-0116896, filed on Sep. 30, 2013, in the Korean Intellectual Property Office, the entire disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND

1. Field

Example embodiments relate to methods and/or apparatuses for reducing noise in an image and/or an image processing apparatus using the same.

2. Description of the Related Art

Technology for manufacturing an image sensor that generates digital images with high resolution is advancing, and these advanced image sensors may be utilized in a camera module applied to a mobile apparatus such as a smartphone. As the resolution of the digital images increases, there is an increasing demand for a clear digital image. An image signal processor (ISP) semiconductor circuit, connected to an image sensor, may affect image quality. For example, the ISP semiconductor circuit may include a noise removal algorithm for reducing noise.

A noise removal algorithm that removes noises based on local means may allocate weights to pixel values pixel values by determining a similarity in the units of pixels. In contrast, a non-local means may allocate weight to pixel values by determining a similarity between local groups that consist of a plurality of pixels (a collection of pixels having a certain size of area with one pixel at a center, hereinafter, referred as a patch). Noise removal algorithm based on non-local means may produce crisp images compared to typical noise removal algorithms, and, therefore, may be employed in various fields in which digital images are used. The noise removal algorithm based on non-local means may also be employed for a depth image that is used to generate a three-dimensional (3D) image, as well as a general or medical image.

SUMMARY

Provided are methods and apparatuses for reducing noise in an image, in which a kernel that gives a weight to a pixel value with respect to determination of a similarity between patches is adaptively changed according to a reference patch, a non-transitory computer-readable storage medium for recording the same, and an image processing apparatus using the same, in which noise in an image is removed according to a noise removal algorithm based on non-local means.

Additional aspects will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented example embodiments.

According to some example embodiments, a method of reducing noise in an image includes: setting a reference patch that consists of a plurality of pixels, having a certain pixel included in the image as a center pixel, and target patches corresponding to the reference patch in the image; determining a similarity between the reference patch and the target patches; and removing noise from a center pixel in the reference patch based on pixel values of center pixels in the target patches, in consideration of a weight based on the similarity between the reference patch and the target patches, wherein a

kernel for giving a weight to a pixel value with respect to the determining of the similarity between the reference patch and the target patches is adaptively changed according to the reference patch.

According to other example embodiments, a non-transitory computer-readable storage medium having stored thereon a computer program, which when executed by a computer, performs the method of reducing noise in an image.

According to other example embodiments, an image processing apparatus for reducing noise in an image includes: a patch setting unit for setting a reference patch that consists of a plurality of pixels, having a certain pixel included in the image as a center pixel, and target patches corresponding to the reference patch in the image; a similarity determination unit for determining a similarity between the reference patch and the target patches; and a noise removal unit for removing noise from a center pixel in the reference patch based on pixel values of center pixels in the target patches, in consideration of a weight based on the similarity between the reference patch and the target patches, wherein a kernel for giving a weight to a pixel value with respect to the determining of the similarity between the reference patch and the target patches is adaptively changed according to the reference patch.

BRIEF DESCRIPTION OF THE DRAWINGS

These and/or other aspects will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings in which:

FIG. **1** is a diagram for explaining a method of reducing noise according to a noise reduction algorithm based on non-local means;

FIG. **2** is a diagram for explaining a kernel for giving a weight to a pixel value when a similarity between patches is calculated by using the noise removal algorithm based on non-local means;

FIG. **3** is a diagram for explaining a pixel value of nearby pixels that are differentiated from the center pixel in a reference patch by using an edge as a boundary;

FIG. **4** is a diagram for explaining a limit in a typical kernel for giving a weight to a pixel value when a similarity between patches is calculated by using the noise removal algorithm based on non-local means;

FIG. **5** is a diagram for explaining a weight according to a similarity between pixel values of the center pixel and nearby pixels in the reference patch, which is applied to the kernel with regard to the method of reducing noise according to the noise reduction algorithm based on non-local means, according to some example embodiments;

FIG. **6** is a diagram of a kernel used in the method of reducing noise in an image according to the noise reduction algorithm based on non-local means, according to some example embodiments;

FIG. **7** is a flowchart of a method of reducing noise in an image according to the noise reduction algorithm based on non-local means, according to some example embodiments;

FIG. **8** is a block diagram of an image processing apparatus for reducing noise in an image according to a noise reduction algorithm based on non-local means, according to some example embodiments;

FIG. **9** is a detailed block diagram of a similarity determination unit that constitutes the image processing apparatus for reducing noise in an image according to the noise removal algorithm based on non-local means, according to some example embodiments; and

FIG. **10** is a graph showing performance when the method of reducing noise in an image according to the noise removal algorithm based on non-local means is performed according to some example embodiments.

DETAILED DESCRIPTION

Reference will now be made in detail to example embodiments, some examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout. In this regard, the example embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Rather, these example embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of example embodiments to those of ordinary skilled in the art. Accordingly, the example embodiments are merely described below, by referring to the figures, to explain aspects of the present description. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

Some example embodiments relate to a method of reducing noise in an image and an image processing apparatus using the same, and descriptions of techniques or structures related to the described example embodiments which would be obvious to one of ordinary skill in the art may be omitted.

It should be understood, however, that there is no intent to limit this disclosure to the particular example embodiments disclosed. On the contrary, example embodiments are to cover all modifications, equivalents, and alternatives falling within the scope of the example embodiments. Like numbers refer to like elements throughout the description of the figures.

It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of this disclosure. As used herein, the term "and/or," includes any and all combinations of one or more of the associated listed items.

It will be understood that when an element is referred to as being "connected," or "coupled," to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly connected," or "directly coupled," to another element, there are no intervening elements present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between," versus "directly between," "adjacent," versus "directly adjacent," etc.).

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the," are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and/or "including," when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

It should also be noted that in some alternative implementations, the functions/acts noted may occur out of the order noted in the figures. For example, two figures shown in succession may in fact be executed substantially concurrently or may sometimes be executed in the reverse order, depending upon the functionality/acts involved.

It should be understood, however, that there is no intent to limit this disclosure to the particular example embodiments disclosed. On the contrary, example embodiments are to cover all modifications, equivalents, and alternatives falling within the scope of the example embodiments. Like numbers refer to like elements throughout the description of the figures.

It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of this disclosure. As used herein, the term "and/or," includes any and all combinations of one or more of the associated listed items.

It will be understood that when an element is referred to as being "connected," or "coupled," to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly connected," or "directly coupled," to another element, there are no intervening elements present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between," versus "directly between," "adjacent," versus "directly adjacent," etc.).

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the," are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and/or "including," when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

It should also be noted that in some alternative implementations, the functions/acts noted may occur out of the order noted in the figures. For example, two figures shown in succession may in fact be executed substantially concurrently or may sometimes be executed in the reverse order, depending upon the functionality/acts involved.

Various example embodiments will now be described more fully with reference to the accompanying drawings in which some example embodiments are shown. In the drawings, the thicknesses of layers and regions are exaggerated for clarity.

FIG. **1** is a diagram for explaining a method of reducing noise according to a noise reduction algorithm based on non-local means. A left image shown in FIG. **1** is an image obtained before noise is removed, and a right image shown in FIG. **1** is a noise-removed image.

Below is described a method of reducing noise according to the noise removal algorithm based on non-local means according to some example embodiments.

Referring to FIG. **1**, a reference patch **100** is set. The reference patch may consist of a plurality of pixels including a center pixel **110** that may have noise therein. Target patches **200** that correspond to the reference patch **100** may be set, and the pixel values of pixels in the target patches **200** may be used to remove noise that is present in the center pixel **110** of the reference patch **100**. For example, center pixels **210** in the target patches **200** may be used to remove noise that is present in the center pixel **110** in the reference patch **100**. When pixel values of the respective center pixels **210** in the target patches **200** are used to remove noise in the center pixel **110** in the reference patch **100**, a weight may be given to each pixel value of the center pixels **210** in the target patches **200** so as to effectively remove noise.

With regard to the method of reducing noise according to the noise removal algorithm based on non-local means, a weight is given to the center pixels **210** based on a similarity between the reference patch **100** and the respective target patches **200**. In other words, a weight that is given to a pixel value of the center pixels **210** in the target patches **200** varies with a degree of a similarity between the reference patch **100** and the target patches **200**. The removal of the noise from the center pixel **110** in the reference patch **100** according to a noise removal algorithm based on non-local means may be expressed as Equation 1.

$$\bar{I}(x_i) = \frac{\sum_{x_j \in \Omega} w(x_i, x_j) I(x_j)}{\sum_{x_j \in \Omega} w(x_i, x_j)} \quad \text{Equation 1}$$

In Equation 1, X_i may be a vector representing a location of a pixel, from which noise is to be removed, in an image, and represents the center pixel **110** in the reference patch **100** in the image. $I(X_i)$ may refer to a pixel value of the center pixel **110** in the reference patch **100**. X_j may be a vector representing a location of a nearby pixel, which is used to remove noise, in the image, and represents the center pixel **210** in the target patch **200** in the image. $I(X_j)$ may refer to a pixel value of the center pixel **210** in the target patch **200**. $I(X_i)$ may refer to a pixel value of a pixel on which noise removal is performed, and refers to a pixel value of the center pixel **110** in the reference patch **100** after noise is removed. Ω may be a collection of all pixels in the image which are used to remove noise, and is a collection of all pixels that may be the center pixel **210** in the target patch **200** in the image. $W(X_i,X_j)$ is a weighting function with respect to the center pixel **210** in the target patch **200** for obtaining a weighted average when noise is removed from the center pixel **110** in the reference patch **100**.

Referring to the left image shown in FIG. **1**, the reference patch **100** and the center pixel **110** in the reference patch **100** are shown, and the target patches **200** are set near the reference patch **100**. The target patch **200**, shown in FIG. **1**, only represents examples of the target patches **200** that are used to remove noise.

Additionally, the center pixels **210** in the target patches **200** respectively have a weight value with respect to the center pixel **110** in the reference patch **100**. The right image, shown in FIG. **1**, is a noise-removed image and shows that noise is removed and an edge is preserved, compared to the left image, shown in FIG. **1**, which is obtained before noise is removed.

The weighing function $W(X_i,X_j)$ of Equation 1 may be expressed as Equation 2 shown below.

$$w(x_i, x_j)\exp\left(-\frac{s(x_i, x_j)}{\sigma^2}\right) \quad \text{Equation 2}$$

In Equation 2, $S(X_i,X_j)$ represents a similarity between the reference patch **100** having X_i as the center pixel **110** and the target patch **200** having X_j as the center pixel **210**. σ is a decay control factor for adjusting a width of the weighing function $W(X_i,X_j)$.

According to the noise-removal algorithm based on non-local means, $S(X_i,X_j)$ may be calculated using Equation 3.

$$s(x_i, x_j) = \sum_{\Delta x \in N} h(\Delta x) \| I(x_i + \Delta x) - I(x_j + \Delta x) \|^2 \quad \text{Equation 3}$$

Δx is a displacement vector that represents a location that is away from the center pixel **110** or **210**. In other words, $X_i+\Delta x$ represents a pixel in a location that is away from a location of X_i by Δx. N represents a size of a patch. A patch may have various sizes N such as 5×5, 11×11, 21×21, or so on.

Referring to $S(X_i,X_j)$ shown in Equation 3, a similarity between the reference patch **100** and the target patch **200** may be calculated by calculating a difference in pixel values between a certain pixel in the reference patch and a pixel corresponding to the certain pixel in the target patch **200** and summing values that are obtained by squaring the calculated difference, with respect to all pixels in the reference patch **100**.

Accordingly, if the two patches are similar, $S(X_i,X_j)$ may have a small value, and if the two patches are not similar, $S(X_i,X_j)$ may have a large value. Referring back to Equation 2, the weighing function $W(X_i,X_j)$ with respect to the center pixel **210** in the target patch **200**, may have a large value if the two patches are similar, and may have a small value if the two patches are not similar. Resultantly, the pixel value $I(X_j)$ of the center pixel **210** in the target patch **200** used to remove noise in an image, is given a weight according to a similarity between the target patch **200**, having X_j as the center pixel **210**, and the reference patch **100**. If the target patch **200** and the reference patch **100** are similar, a high weight may be given to the pixel value $I(X_j)$ of the center pixel **210** in the target patch **200**.

Referring back to Equation 3, a function h(Δx) is further used when a similarity between the reference patch **100** and the target patch **200** is calculated. The function h(Δx) may be a kernel that gives a weight to a pixel value based on a similarity between the reference patch **100** and the target patch **200** such that a value of h(Δx) changes according to Δx. Since nearby pixels generally have a similar pixel value, a higher weight may be given to nearby pixels. Therefore, the function h(Δx) gives a high weight to a pixel value of the pixel if the pixel is near the center pixel **110** in the patch **110**, and gives a low weight to a pixel value if the pixel is far from the center pixel **110** in the patch **110**.

For example, the function h(Δx) may be a Gaussian kernel, and, therefore, h(Δx) may be expressed as Equation 4 shown below.

$$h(\Delta x) = \exp\left(-\frac{\Delta x^2}{\gamma}\right) \quad \text{Equation 4}$$

γ is a constant for adjusting a width of the kernel h(Δx). Hereinafter, referring to FIG. **2**, the kernel h(Δx) is described in detail.

FIG. **2** is a diagram for explaining a kernel for giving a weight to a pixel value when a similarity between patches is calculated by using the noise removal algorithm based on non-local means.

Referring to FIG. **2**, the kernel $h(\Delta x)$, shown in FIG. **2**, is a function in which a value changes according to Δx. If a value of Δx is high, a value of $h(\Delta x)$ may be small. Accordingly, when a similarity between the reference patch **100** and the target patch **200** is calculated, a high weight is given to a pixel value if a value of Δx is small.

In other words, the kernel $h(\Delta x)$ is a weighting function whose effectiveness depends on the assumption that nearby pixels have a similar pixel value. If such an assumption is not satisfied, a weight that is given to a pixel value by using the kernel $h(\Delta x)$ may be limited in its ability to effectively remove noise.

Hereinafter, referring to FIGS. **3** and **4**, a problem of the typical kernel for giving a weight to a pixel value when a similarity between patches is calculated according to the noise removal algorithm based on non-local means is described.

FIG. **3** is a diagram for explaining a pixel value of nearby pixels that are differentiated from the center pixel **110** in the reference patch **100** by using an edge as a boundary.

FIG. **3** shows an image in which a part of the reference patch **100** in the left image, shown in FIG. **1**, is expanded. Referring to FIG. **3**, pixel values of two parts which are divided by an edge in the reference patch **100** are different from each other. The center pixel **110** is included in a right part from among the both parts that are divided by the edge.

Referring to FIG. **3**, a line A passing through the center pixel **110** in the reference patch **100** is set, and a line of pixels that include the center pixel **110** X_i, included in the line A, may be identified. A pixel X_α and a pixel X_β, which are on the line A equidistant from the center pixel **110** X_i, are shown in FIG. **3**. With reference to the edge, the pixel X_α is located in a left part with respect to the edge, and the pixel X_β is located in a right part with respect to the edge. In other words, the pixel X_α and the pixel X_β are away from the center pixel **110** X_i at a same distance, but since the edge is present between the pixel X_α and the pixel X_β, the pixel X_α and the pixel X_β are separate in the left part and the right part with respect to the edge.

Since the edge corresponds to a boundary for dividing areas having different pixel values from each other, pixel values of the areas divided by the edge may be different from each other. As shown in FIG. **3**, since the center pixel **110** X_i and the pixel X_β are in the right part with respect to the edge, the center pixel **110** X_i and the pixel X_β may have similar pixel values. However, the pixel X_α is in the left part with respect to the edge, the pixel X_α may have a pixel value that is different from pixel values of the center pixel **110** X_i and the pixel X_β.

However, even though the pixel X_α may have a different pixel value, when utilizing the kernel $h(\Delta x)$ described with reference to FIG. **2**, since the pixel X_α and the pixel X_β are away from the center pixel **110** at a same distance, the pixel X_α and the pixel X_β may be given a same weight. This potential problem is described in detail with reference to FIG. **4**.

FIG. **4** is a diagram for explaining a limit in a typical kernel for giving a weight to a pixel value when a similarity between patches is calculated by using the noise removal algorithm based on non-local means.

Referring to FIG. **4**, the typical kernel $h(\Delta x)$, shown in FIG. **4**, is a symmetrical version of the typical kernel $h(\Delta x)$ shown in FIG. **2**. In other words, for the same values of locations Δx away from the center pixel **110**, a value of $h(\Delta x)$ may also be the same. The pixel X_α and the pixel X_β that are on the line A at a same distance away from the center pixel **110** X_i, described with reference to FIG. **3**, have the same $h(\Delta x)$ value as shown in FIG. **4**, and thus, a same weight is given to the pixel X_α and the pixel X_β.

However, as described with reference to FIG. **3**, since an edge in which pixel values vary may be present between the pixel X_α and the pixel X_β, pixel values of the pixel X_α and the pixel X_β may have a great difference from each other. Accordingly, since only a location away from the center pixel **110** X_i is taken into account in the typical kernel $h(\Delta x)$, the typical kernel $h(\Delta x)$ may not accurately remove noise.

FIG. **5** is a diagram for explaining a weight according to a similarity between pixel values of the center pixel **110** and periphery pixels in the reference patch **100**, which is applied to the kernel with regard to the method of reducing noise according the noise reduction algorithm based on non-local means, according to some example embodiments.

Referring to FIG. **5**, according to some example embodiments, with regard to the method of reducing noise according to the noise reduction algorithm based on non-local means, a kernel is designed to further take into account a similarity between pixel values of the center pixel **110** and nearby pixels in the reference patch **100**, so as to overcome the limit in the typical kernel that is described above.

For example, a weighting function $F(I(X_i), \Delta x)$, which varies according to a similarity between a pixel value of the center pixel **110** X_i and a pixel value of a nearby pixel in the reference patch **100**, is further included.

Referring back to the image of the reference patch **100** described above with reference to FIG. **3**. In the image of the reference patch **100**, the pixel X_α, the center pixel **110** X_i, and the pixel X_β are on the line A that passes through the center pixel **110** X_i. As illustrated in FIG. **3**, the edge in which pixel values vary may be present between the pixel X_α and the center pixel **110** X_i. For convenience of description, it is assumed that all pixels in a left area with respect to the edge have a pixel value of 'a', and all pixels in a right area with respect to the edge have a pixel value of 'b', however, example embodiments are not limited thereto. Thus, a pixel value of the pixel X_α is 'a', and the pixel value of the pixel X_β and of the center pixel **110** X_i is 'b'. Accordingly, a pixel value of the pixel X_α has a difference of 'b−a' from a pixel value of the center pixel **110** X_i, and a pixel value of X_β has no difference from a pixel value of the center pixel **110** X_i.

Based on such a similarity between pixel values, the weighting function $F(I(X_i), \Delta x)$ shown in FIG. **5**, which varies according to a similarity between a pixel value of the center pixel **110** X_i, may be employed. Referring to FIG. **5**, since an edge is present in a left part with respect to the center pixel **110** X_i, weights of pixels, which are divided into both parts with respect to a pixel on a line A included in the edge, are different from each other.

In other words, according to the weight function $f(I(X_i), \Delta x)$ based on a similarity between pixel values, pixels in a same area as the center pixel **110** X_i in the right part with respect to the edge have a high weight, and pixels in a different area from the center pixel **110** X_i in the left part with respect to the edge have a low weight.

Hereinafter, a kernel used in the method of reducing noise in an image according to the noise reduction algorithm based on non-local means and designed by further taking into account a similarity between pixel values is described.

FIG. **6** is a diagram of a kernel used in the method of reducing noise in an image according to a noise reduction algorithm based on non-local means, according to some example embodiments.

Referring to FIG. **6**, a kernel $h'(I(X_i), \Delta x)$, shown in FIG. **6**, represents a kernel used with regard to the image of the reference patch **100** described with reference to FIGS. **3** and **5**, according to some example embodiments.

With regard to the kernel h'(I(X_i), Δx), the weight f(I(X_i), Δx) according to a similarity between pixel values is further taken into account, compared to the typical kernel h(Δx). Resultantly, the kernel h'(I(X_i), Δx) may be generated by multiplying the function described with reference to FIG. **4** by the function described with reference to FIG. **5**. According to the kernel h'(I(X_i), Δx), even when pixels are at a same distance away from the center pixel **110** X_i, a different weight may be given to the pixels according to a pixel value. Therefore, a greater weight may be given to the pixel X_β and less weight may be given to the pixel X_α as compared to when the typical kernel h(Δx) described with reference to FIG. **4** is employed. According to some example embodiments, the kernel h'(I(X_i), Δx) employed in the method of reducing noise in an image according to the noise removal algorithm based on non-local means may be expressed as Equation 5 shown below.

$$h'(I(x_i), \Delta x) = f(I(x_i), \Delta x) \cdot \exp\left(-\frac{\Delta x^2}{\gamma}\right) \qquad \text{Equation 5}$$

In Equation 5, f(I(X_i), Δx) represents the weight according to the similarity between pixel values, and may be expressed as Equation 6 shown below.

$$f(I(x_i), \Delta x) = 1 - \frac{\|I(x_i) - I(x_i + \Delta x)\| - V_{min}}{V_{max} - V_{min}} \qquad \text{Equation 6}$$

In Equation 6, V_{max} represents a maximum value from among difference values between the center pixel **110** and a nearby pixel in the reference patch **100**. V_{min} represents a minimum value from among difference values between the center pixel **110** and a nearby pixel in the reference patch **100**. V_{max} and V_{min} may be expressed by Equations 7 and 7, respectively, as shown below.

$$V_{max} = \max_{\Delta x \in N} \|I(x_i) - I(x_i + \Delta x)\| \qquad \text{Equation 7}$$

$$V_{min} = \min_{\Delta x \in N} \|I(x_i) - I(x_i + \Delta x)\| \qquad \text{Equation 8}$$

Accordingly, the kernel h'(I(X_i), Δx) employed in the method of reducing noise in an image according to the noise removal algorithm based on non-local means may be adaptively changed according to the reference patch **100** and may be adaptively changed according to a distribution of pixel values in the reference patch **100**.

Additionally, as shown in Equation 5, the kernel h'(I(X_i), Δx) may be adaptively changed according to a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**. For example, the kernel h'(I(X_i), Δx) gives a high weight to a pixel value, if a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** is high.

In other words, according to some example embodiments, the kernel h'(I(X_i), Δx) may be generated in consideration of both a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** and a location difference between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**.

Additionally, as shown in Equation 6, the kernel h'(I(X_i), Δx) may be generated by taking into account difference values between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** and employing a maximum value and a minimum value from among the difference values.

For example, the kernel h'(I(X_i), Δx) may be generated by using a value, which is obtained by normalizing difference values between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patches **100** by using a maximum value and a minimum value from among the difference values therebetween. In other words, using Equation 6, a weight according to a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** may be normalized to a value between 0 and 1.

FIG. **7** is a flowchart of a method of reducing noise in an image according to the noise reduction algorithm based on non-local means, according to some example embodiments.

Referring to FIG. **7**, in operation S**710**, the reference patch **100** that consists of a plurality of pixels, having a certain pixel included in an image as the center pixel **110**, and target patches **200** that correspond to the reference patch **100** in the image are set. The reference patch **100** may be set respectively for all pixels included in the image. In other words, a reference patch having the pixel at a center may be set respectively according to a pixel from which noise is to be removed. Accordingly, a distribution of pixel values included in each of the reference patches may be changed each time according to a pixel from which noise is to be removed.

In operation S**720**, a similarity between the reference patch **100** and the target patches **200** is determined. When the similarity between the patches is determined, a kernel for providing a weight is employed. According to some example embodiments, a kernel may be adaptively changed according to the reference patch **100** and may be adaptively changed according to a distribution of each pixel value of the reference patch **100**.

Additionally, according some example embodiments, a kernel may be adaptively changed according to a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**. For example, the kernel may give a high weight to pixel values, if a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** is high. In other words, the kernel may be generated in consideration of both a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** and a location difference between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**.

Additionally, according to some example embodiments, the kernel may be generated by taking into account difference values between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** and using a maximum value and a minimum value from among the difference values. For example, the kernel may be generated by using a value, which is obtained by normalizing difference values between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patches **100** by using a maximum value and a minimum value from among the difference values therebetween. In other words, a weight according to a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** may be normalized to a value between 0 and 1.

In step **730**, noise in the center pixel **110** in the reference patch **100** is removed based on pixel values of the center pixels **210** in the target patches **200**, in consideration of a weight based on the similarity between the patches.

According to some example embodiments, with regard to the method of reducing noise in an image according to the noise reduction algorithm based on non-local means, noise may be removed by further employing an image adjacent to the image from which noise is to be removed. The noise may be removed in view of the adjacent image based on Equation 9, shown below.

$$\tilde{I}(x_i^n) = \frac{\sum_{\Delta n} \sum_{x_j \in \Omega} w(x_i^n, x_j^{n+\Delta n}) I(x_j^{n+\Delta n})}{\sum_{\Delta n} \sum_{x_j \in \Omega} w(x_i^n, x_j^{n+\Delta n})} \quad \text{Equation 9}$$

In Equation 9, n represents a frame number of a current image and Δn represents a difference between the frame number n of the current image and a frame number of an adjacent image that will be further used to remove noise. In other words, if Δn is −1, 0, and 1, images of a current frame, a previous frame, and a next frame are used to remove noise from the current frame.

FIG. **8** is a block diagram of an image processing apparatus **800** for reducing noise in an image according to the noise reduction algorithm based on non-local means, according to an embodiment of the present disclosure. It may be understood by one of ordinary skill in the art that, in addition to elements shown in FIG. **8**, other elements may be further included.

The method of reducing noise in an image according to the noise removal algorithm based on non-local means, as discussed above with reference to FIG. **7**, may be performed by the image processing apparatus **800** according to some example embodiments.

Referring to FIG. **8**, the image processing apparatus **800** for reducing noise in an image may include a processor and a memory (not shown).

The processor may be an arithmetic logic unit, a digital signal processor, a microcomputer, a field programmable array, a programmable logic unit, a microprocessor or any other device capable of responding to and executing instructions in a defined manner such that the processor is programmed with instructions that configure the processor as a special purpose computer to perform the operations illustrated in FIG. **7**, such that the processor is configured to give weight to pixel values in consideration of both a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** and a location difference between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**.

The patch setting unit **810** sets the reference patch **100** that consists of a plurality of pixels, having a certain pixel included in an image as a center pixel **110**, and the target patches **200** that correspond to the reference patch **100** in the image. The reference patch **100** may be set respectively for all pixels included in an image. In other words, according to a pixel from which noise is to be removed, a respective reference patch **100** having the pixel at a center may be set. Accordingly, a distribution of pixel values included in the respective reference patch **100** may be changed each time according to a pixel from which noise is to be removed.

The image processing apparatus **800** may include a patch setting unit **810**, a similarity determination unit **820**, and a noise removal unit **830**. For example, the processor may be configured to execute instructions that program the processor to perform the functions of one or more of the patch setting unit **810**, the similarity determination unit **820**, and the noise removal unit **830**.

The similarity determination unit **820** determines a similarity between the reference patch **100** and the target patches **200**. Hereinafter, referring to FIG. **9**, the similarity determination unit **820** is described in detail.

FIG. **9** is a detailed block diagram of the similarity determination unit **820** that constitutes the image processing apparatus **800** for reducing noise in an image according to the noise removal algorithm based on non-local means, according to some example embodiments.

Referring to FIG. **9**, the similarity determination unit **820** may include a pixel value calculation unit **822**, a kernel generation unit **824**, and a pixel similarity calculation unit **826**.

The pixel value calculation unit **822** sums values that are obtained by calculating a difference in pixel values between a certain pixel in the reference patch **100** and a pixel corresponding to the certain pixel in the target patch **200** and squaring the calculated difference, with respect to all pixels in the reference patch **100**, so as to determine a similarity between the reference patch **100** and the target patch **200**.

The kernel generation unit **824** generates a kernel that gives a weight to a difference in pixel values between a certain pixel in the reference patch **100** and a pixel corresponding to the certain pixel in the target patch **200**, calculated by the pixel value calculation unit **822**. According to some example embodiments, the kernel generation unit **824** may adaptively change the kernel according to the reference patch **100** and may be adaptively change the kernel according to a distribution of each pixel value in the reference patch **100**.

For example, the kernel generation unit **824** may adaptively change the kernel according to a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**. This is because a high weight is given to pixel values, if a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** is high. The kernel generation unit **824** may generate the kernel in consideration of both a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** and a location difference between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**.

According to some example embodiments, the kernel generation unit **824** may generate the kernel by taking into account difference values between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** and using a maximum value and a minimum value from among the difference values. In detail, the kernel generation unit **824** may generate the kernel by using a value, which is obtained by normalizing difference values between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patches **100** by using a maximum value and a minimum value from among the difference values therebetween. In other words, the kernel generation unit **824** may normalize a weight according to a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** to a value between 0 and 1.

The pixel similarity calculation unit **826** calculates a similarity between pixels so that the kernel generation unit **824** generates a kernel. In other words, the pixel similarity calculation unit **826** may calculate a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**. For example, the pixel similarity calculation unit **826** may calculate a similarity between pixels by calculating a difference value between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**. The kernel generation unit **824** may use the difference value, calculated by the pixel similarity calculation unit **826**, to generate the kernel.

Resultantly, when a similarity between the reference patch **100** and the target patch **200** is determined, the similarity determination unit **820** may use the kernel to give a weight to pixel values in consideration of both a similarity between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100** and a location difference between the center pixel **110** in the reference patch **100** and nearby pixels in the reference patch **100**.

Referring back to FIG. **8**, the noise removal unit **830** removes noise in the center pixel **110** in the reference patch **100** based on the pixel values of the center pixels **210** in the target patches **200**, in consideration of the weight based on the similarity between patches.

According to some example embodiments, the image processing apparatus **800** for reducing noise in an image according to the noise removal algorithm based on non-local means may remove noise in a medical image or a depth image that shows a distance between an image photographing apparatus and a subject, as shown in FIG. **1**, as well as in a general image.

FIG. **10** is a graph showing performance when the method of reducing noise in an image according to the noise removal algorithm based on non-local means is performed according to some example embodiments.

Referring to FIG. **10**, an image that is input before noise is removed, is shown as INPUT, an image in which noise is reduced according to the typical noise removal algorithm based on non-local means, is shown as NLM in FIG. **10**, and an image in which noise is reduced according to the noise removal algorithm based on non-local means according to some example embodiments, is shown as ANLM in FIG. **10**. A root mean square error (RMSE) is employed to calculate an error in the images caused by noise.

As shown in FIG. **10**, an RMSE value of the image ANLM in which noise is reduced according to the noise removal algorithm based on non-local means, according to some example embodiment, is smaller than an RMSE value of the image NLM in which noise is reduced according to the typical noise removal algorithm based on non-local means. Thus, the image processing apparatus **800**, which utilizes the noise removal algorithm based on non-local means, according to some example embodiments, may have improved noise removal capabilities.

As described above, according to the one or more of the above example embodiments, an edge in an image is preserved and noise removal performance may be improved.

In addition, example embodiments can also be implemented through computer-readable code/instructions in/on a medium, e.g., a non-transitory computer-readable medium, to control at least one processing element to implement any above-described embodiment. The medium can correspond to any medium/media permitting the storage and/or transmission of the computer-readable code.

The computer-readable code can be recorded/transferred on a medium in a variety of ways, with examples of the medium including recording media, such as magnetic storage media (e.g., ROM, floppy disks, hard disks, etc.) and optical recording media (e.g., CD-ROMs, DVDs, etc.), and transmission media such as Internet transmission media. Thus, the medium may be such a defined and measurable structure including or carrying a signal or information, such as a device carrying a bitstream according to one or more embodiments of the present disclosure. The media may also be a distributed network, so that the computer-readable code is stored/transferred and executed in a distributed fashion. Furthermore, the processing element could include a processor or a computer processor, and processing elements may be distributed and/or included in a single device.

It should be understood that the example embodiments described therein should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each example embodiment should typically be considered as available for other similar features or aspects in other embodiments.

While one or more example embodiments have been described with reference to the figures, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the example embodiments as defined by the following claims.

What is claimed is:

1. A method of reducing noise in an image, the method comprising:

setting a plurality of pixels in the image as a reference patch, and setting target patches in the image corresponding to the reference patch, the reference patch having a center pixel;

determining a similarity within the reference patch between the center pixel in the reference patch and nearby pixels in the reference patch;

adaptively setting a kernel based on the similarity within the reference patch;

determining a similarity between the reference patch and the target patches using the kernel; and

removing noise from the center pixel in the reference patch based on pixel values of center pixels in the target patches by applying, a weight to the center pixels of the target patches based on the similarity between the reference patch and the target patches.

2. The method of claim **1**, wherein the kernel is adaptively changed according to a distribution of pixel values of the reference patch.

3. The method of claim **1**, wherein the kernel gives a relatively high weight to a pixel value of the center pixel in the reference patch, if a similarity between the center pixel in the reference patch and the nearby pixels is high.

4. The method of claim **1**, wherein the kernel is generated based on difference values between the center pixel in the reference patch and the nearby pixels in the reference patch that are close to the center pixel and a maximum one of the difference values and a minimum one of the difference values.

5. The method of claim **4**, wherein the kernel is generated by normalizing the difference values between the center pixel in the reference patch and the nearby pixels using the maximum value and the minimum value.

6. The method of claim **4**, wherein the kernel is generated based on location differences from the center pixel in the reference patch to the nearby pixels.

7. The method of claim **1**, wherein the determining the similarity between the reference patch and the target patches further comprises:

calculating a difference between pixels in the reference patch and pixels in the target patch that corresponds to the pixels in the reference patch.

8. The method of claim **1**, wherein the setting sets the target patches in images adjacent in an image sequence to the image.

9. A non-transitory computer-readable storage medium having stored thereon a computer program, which when executed by a computer, configures the computer to perform the method of claim **1**.

10. An image processing apparatus configured to reduce noise in an image, the image processing apparatus comprising:

a processor configured to,

set a plurality of pixels in the image as a reference patch, and to set target patches in the image corresponding to the reference patch, the reference patch having a center pixel,

determine a similarity within the reference patch between the center pixel in the reference patch and nearby pixels in the reference patch,

adaptively set a kernel based on the similarity within the reference patch,

determine a similarity between the reference patch and the target patches using the kernel, and

remove noise from the center pixel in the reference patch based on pixel values of center pixels in the target patches by applying a weight to the center pixels of the target patches based on the similarity between the reference patch and the target patches.

11. The image processing apparatus of claim **10**, wherein the processor is configured to adaptively change the kernel according to a distribution of pixel values of the reference patch.

12. The image processing apparatus of claim **10**, wherein the kernel gives a relatively high weight to a pixel value of the center pixel in the reference patch if a similarity between the center pixel in the reference patch and the nearby pixels is high.

13. The image processing apparatus of claim **10**, wherein the processor is configured to generate the kernel based on difference values between the center pixel in the reference patch and the nearby pixels in the reference patch that are close to the center pixel and a maximum one of the difference values and a minimum one of the difference values.

14. The image processing apparatus of claim **13**, the processor is configured to generate the kernel by normalizing the difference values between the center pixel in the reference patch and the nearby pixels using the maximum value and the minimum value.

15. The image processing apparatus of claim **13**, wherein the processor is configured to generate the kernel based on location differences from the center pixel in the reference patch to the nearby pixels.

16. The image processing apparatus of claim **10**, wherein the processor is configured to further calculate a difference between pixels in the reference patch and pixels in the target patch that corresponds to the pixels in the reference patch.

17. The image processing apparatus of claim **10**, wherein the processor is configured to further set the target patches in images adjacent in an image sequence to the image.

18. The image processing apparatus of claim **10**, wherein the image is a depth image representing a distance between an image photographing apparatus and a subject.

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